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Enabling a sustainable Fourth Industrial Revolution: how G20 countries can create the conditions for emerging technologies to benefit people and the planet

Celine Herweijer, Benjamin Combes, Leo Johnson, Rob McCargow, Sahil Bhardwaj, Bridget Jackson, Pia Ramchandani

Abstract
The Fourth Industrial Revolution (4IR) offers huge potential to transform and realign our economies and societies. There is an increasing realization that the 4IR could also exacerbate problems for people and the planet. The G20 should champion a holistic approach to the 4IR that helps to address society's environmental and social challenges. This means both mitigating unintended adverse consequences of change and maximizing positive social and environmental benefits. The G20 should explore, and recommend, governance structures and policy mechanisms to ensure governments have the agility and ability to keep pace with the 4IR, and harness innovations that promise the greatest social and environmental returns.

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Authors
Celine Herweijer, PwC UK
Benjamin Combes, PwC UK
Leo Johnson, PwC UK
Rob McCargow, PwC UK
Sahil Bhardwaj, PwC US
Bridget Jackson, PwC UK
Pia Ramchandani, PwC US

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Challenge

As part of PwC's overarching narrative for the T20, we discuss how three drivers of change – globalisation, technological advances and "financialisation" – have historically served humanity well by typically delivering both economic growth and social progress. However as these drivers have accelerated, evolved and become intertwined over time, divergence between economic growth and social progress has occurred placing people and the planet under substantial strain. In this paper we look forward to how today's technological-driven revolution – the Fourth Industrial Revolution (4IR)[1] – can course correct this trend, with the right governance, enabling environment and public-private partnerships.

Humanity stands at an important moment in history. The global, digitally-enabled 4IR is already the fastest period of innovation ever. It is underpinned by rapid advances in technologies including artificial intelligence (PwC 2016), robotics, the internet of things, nanotechnology and biotechnology, to name a few. The disruption of many traditional markets and industries is already underway. How can we shape these transformations to address society's and the Earth's most pressing challenges, and not exacerbate them?

Previous industrial revolutions advanced economic development but have largely come at the expense of the planet. Today there is mounting scientific consensus that Earth's systems are under unprecedented stress. Scientists at the Stockholm Environment Institute have identified that four out of the Earth's nine 'Planetary Boundaries' have already been crossed, namely climate, biodiversity, land-system change and biogeochemical cycles (Steffen et al., 2015). Risks will only heighten as population swells to a projected 9 billion by 2050, increasing food, materials and energy needs. In parallel, society today is under growing social and economic strain, from mounting inequality, youth unemployment, automation, geopolitical volatility and nationalism.

These global challenges of today are framed by the UN's 17 Global Goals for Sustainable Development (SDGs) (United Nations, 2017b). Agreed by 193 countries in 2015, the SDGs provide an action agenda for people and the planet out to 2030. There is a window of opportunity now, to make the sweeping advances of the 4IR help governments, business and society to achieve these goals, not make them harder to attain.

For governments and policy makers, it is vital that the enabling mechanisms are put in place for the 4IR to be a sustainable revolution. The innovations and economic value unlocked by the 4IR must maximise positive social and environmental impacts, and avoid exacerbating today's most pressing challenges. The governance challenge is even greater than in previous industrial revolutions due to the complexity, pace, and global and sectoral breadth of change. Zero-cost digital distribution today enables products and services to penetrate the mainstream and 'go global' in a matter of months, with policy and regulation often struggling to keep up. One example of this challenge is the high profile OECD BEPS initiative now being implemented to

[1] Schwab, K. (2016).

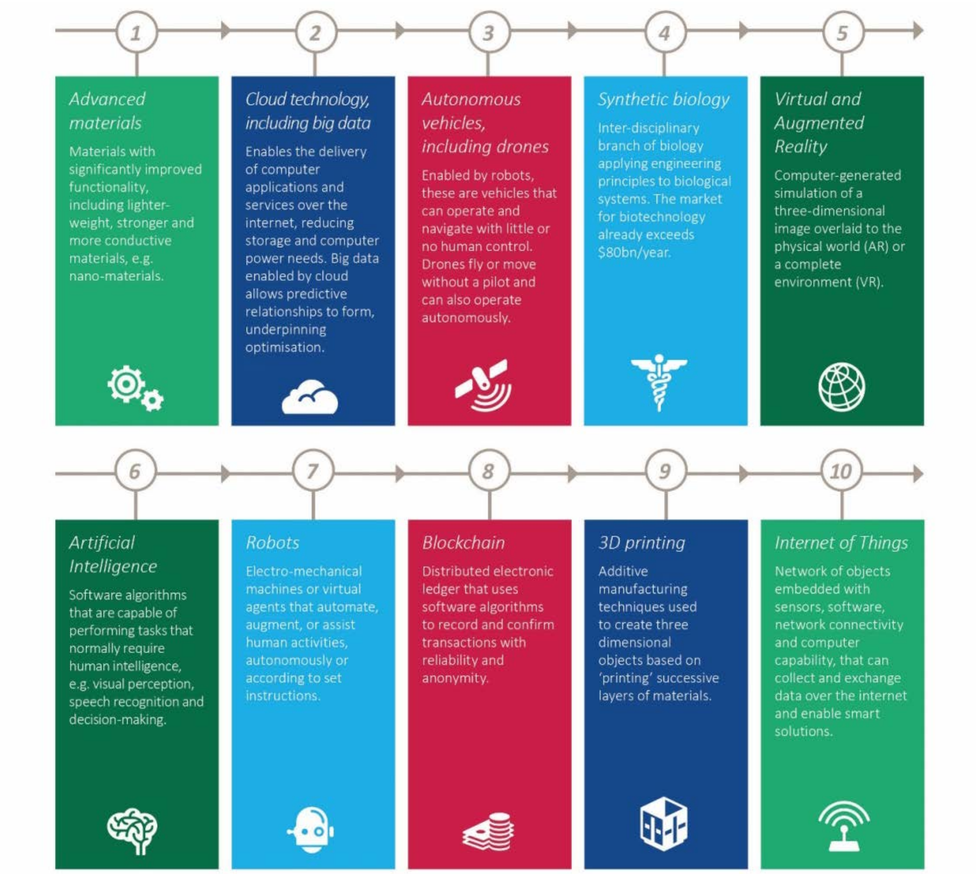
address tensions in the international tax system created in part by the impact of technology on business and how multinational companies invest (OECD, 2017).

For the 4IR to be the first sustainable industrial revolution, governments and regulators will need to adapt quickly with the rapidly evolving 4IR landscape and provide the enabling environment, safeguards, investment and oversight to guide the future that is being built. Support and partnerships will be needed to unlock and scale innovation on emerging - and potentially game-changing - technologies and solutions for people and the planet. And foresight, public policies and technological governance will be needed to avoid or minimise unintended consequences and protect public interests.

Proposal

Amid a rapidly changing innovation landscape, we have identified 10 emerging 4IR technologies that we think could individually and collectively have the greatest impact on jobs, livelihoods, and environments (Figure 1).

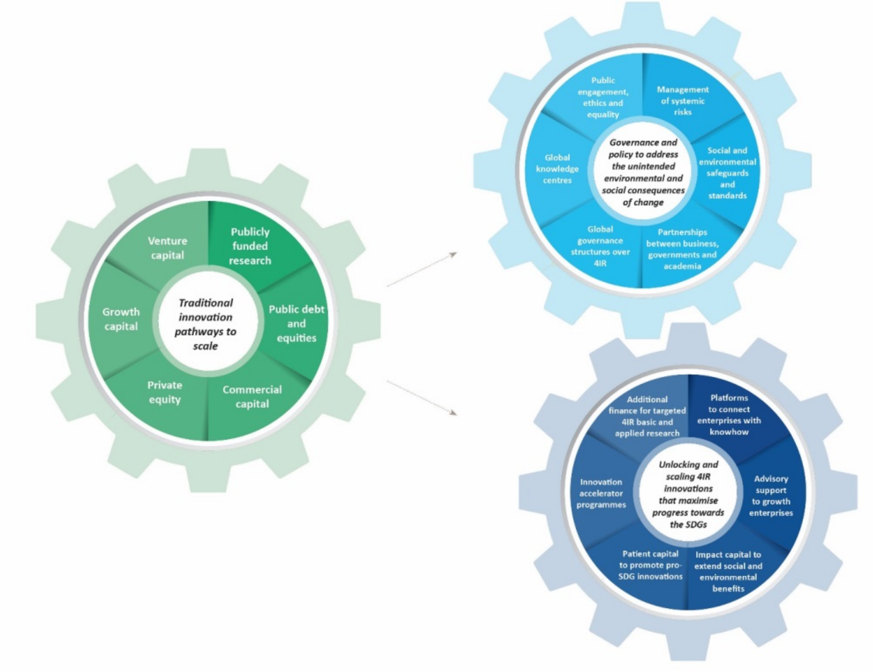
Figure 1: Ten emerging 4IR technologies for the Earth



Source: PwC (2017b).

To harness the potential that these technologies promise for people and the planet, governments and policy makers need to go beyond simply accelerating innovation, and take a more comprehensive approach. This includes: (a) building the global governance structures and policy mechanisms to address the unintended environmental and social consequences of change; and (b) unlocking and scaling 4IR innovations that maximise progress towards the SDGs - including innovations that respond to the new risks and challenges presented by the 4IR itself (Figure 2). In practice, this will often involve 'open innovation' across the full ecosystem of actors, collaborating to develop and shape our future world.

Figure 2: A comprehensive response to the pace and scale of 4IR innovation



Source: PwC

Policy and governance responses to mitigate negative risks and impacts of the 4IR

We have identified four areas where the 4IR poses governance challenges and opportunities that are unlike the previous three industrial revolutions (the third starting almost 40 years ago). First, the 4IR is moving at lightning speed driven by exponential computing power, the internet, mobile infrastructure, and global competition. By contrast, governance structures typically move at a much slower, analogue, pace. There is therefore the potential for governance, policy and regulation to lag far behind new systems, industries and solutions in the 4IR. Second, trust in society of institutions is at post-WWII lows in many western economies; fear of what technology might do for jobs, livelihoods, and society is also rising. Third, the environmental and social impacts of technology on sectors, labour markets, activities, and products is better understood now than during previous industrial revolutions. Finally, through the global connectivity and reach enabled by the digital platforms, social networks, and technologies which underpin the 4IR, coherence and effectiveness of policy, and oversight across borders, is increasingly challenging in the absence of a global regime for technological governance.

Given these four overarching considerations, it will be essential for international organisations and national governments to explore this topic more fully across a range of areas. Importantly, governance structures will need to be updated and refocused to keep pace with the rapidly-developing 4IR-enabled digital economy. In particular, as 4IR technologies are designed, deployed and scaled, environmental and social impacts will need to be considered upfront to minimise harmful unintended consequences and to embed resilience and sustainability in emerging global systems.

A number of mainstream 4IR advances could have unintended negative consequences, or introduce negative risks, that need to be minimised. Below is a selection of illustrative examples of emerging technologies, potential unintended consequences, and examples of the roles of public policy (Table 1).

Table 1: Selected 4IR technologies, example unintended consequences, and potential policy responses

Emerging technology	Example unintended consequences	Role of public policy
Artificial Intelligence	• Automation leading to reduced jobs in services and other sectors with a potential to exacerbate rising inequity in society. Adoption of automation at varying speeds can also impact the GDP share of each industry, increasing fragility of the economy. • Tax base eroded as the current system is based on people in a national state 'bricks-and-mortar' world and is struggling to keep pace with the globalised digital economy. • Technological proliferation driving down the prices of goods and services. • Ethical concerns arising from inherent biases contained within the datasets used to train algorithms, could result in the amplification of discriminatory decision making. • Development of new ethical dimemmas not thoughts about before e.g. accountability and liability as regards incorrect autonomous medical diagnosis or accidents caused by autonomous vehicles • 'Misuse of AI' concerns as many of the algorithms being developed with a good goal (e.g. autonomous vehicles) can be repurposed for harm (e.g. autonomus weaponry), which raises new risks for global safety.	• Structural policy initiatives to ensure that resources and employment can flow between sectors so that those whose jobs (or activities) are most at risk of automation are proactively retrained. • A re-think as to how workforces are trained as people need to retool almost continuously as AI becomes more advanced. • A re-evaluation of the tax system will be required as automation changes the tasks which workers will do and potentially reduces the number of jobs available. How tax is collected will also need to be modernised - this may include blockchain applications. • Universal Basic Income is one of a number of options being explored in several countries. • The development of 'responsible AI' frameworks are now gaining momentum driven by several global and country-level initiatives. • Governance to create explainability, transparency and validity in the algorithms, including drawing lines between beneficial and harmful AI. • Public policy also has an increasingly important role to play in data ownership, privacy and security.

Internet of Things	• Significant increase in energy use from the expanding network of 23 billion connected energy-consuming devices today to 50 billion by 2020, energy efficiency must become a critical common feature of this vast network of devices, sensors and appliances, including responsible disposal of the increased amount of devices. • Increased vulnerability to data breaches and cyber security issues, given the huge connected network of less secure devices and advances in Botnets and malware enabling access and manipulation of more sensitive areas of the network for fraud and cybercrime. E.g. targeting an oil refinery, power plant, online accounts, or even one's home. • Brittleness of IoT dependent system to network and / or grid failure.	• Government-led standards and incentives to limit and, over time, reduce energy consumption from devices, sensors and appliances. • Government can work alongside industry and ICT sector leadership, e.g. GeSI25 (GeSI, 2017). to contribute to increasing the role of renewable energy sources in the energy mix. • Cybersecurity and data privacy need to be addressed. Government-led standards around IoT device security should be strongly considered. • Measures to upcycle rather than recycle resources used.
Blockchain	• Large amounts of energy used in the mining process behind its most popular cryptocurrency – Bitcoin. The Bitcoin mining process requires 'proof of work' (POW) protocols that by design necessitate increasingly powerful computers and dedicated data centres as more miners join, which in turn increases energy consumption. • Tracking provenance in some industries, to authenticate products and remove counterfeits, could significantly increase costs in developing countries (e.g. for medicines). • Growth of shadow-economies that are difficult to regulate and control.	• Government-led standards and policies to standardise 'Proof of Concept' (POC) to lower energy consumption solutions and enable access to a global distributed ledger. • Regulation to secure and standardise digital identity input to authenticate users. This digital identity data must be managed by a trusted party, otherwise data exploitation might prevail.

Autonomous Vehicles (land based)	• Job losses, including for many taxi and lorry drivers, as traditional occupations become increasingly obsolete. • Inequality could rise as AVs replace a swathe of traditional low to medium-skilled roles while the AV sector is likely to provide fewer, but higher-skilled, alternatives. • Potential rebound effect where demand for car-related travel could increase due to convenience and enhanced affordability of AVs. • Mass transport demand could decline as single use AVs become more desirable and AV ride services more affordable. • Pollution and congestion could rise if the absolute number of AV combustion-engine vehicle kilometres increases. • Property prices could be impacted as AVs change the location in which people choose to live e.g. longer commutes could become more appealing if car travel time is productive.	• Policies to address the structural shifts and distribution effects of changing employment patterns. This could include retraining policies for drivers who lose their jobs to provide opportunities and openings in other sectors. • Government policy to manage the air pollution and climate-related impacts of AVs. This may well include standards to ensure AV fleets are low or zero emissions. • Investment in 'smart city' infrastructure and technology, to maximise AV efficiency e.g. through the promotion of car sharing. • Introduction of policies related to AV security and safety (both cyber and physical). • Government guidance on liability implications or AVs. Investment in connected urban mobility systems to counteract potential increase in vehicle numbers with optimised transport routing and management.
Drones	• Drones invading people's personal space/privacy creating demand for a policy framework to address those consequences. • Increased noise pollution from propeller-based drones flying at low altitude. • Spying and / or terrorism threats from drones being used as a medium for nuisance or attack. • Loss of specialist jobs e.g. sewage cleaner, pipelines monitoring etc. due to use of drones coupled with specialised equipment.	• Government policy to manage drone noise pollution, creating a framework for licensing, registration and safe operations. • Aviation regulators creating droneways/drone highways or setting operational aspects of where drones can fly. • Health and safety framework for drone deployment and usage. • 3D mapping policy to ensure there is a relevant structure in place to help capture national survey information.
Cloud services	• Hyper-scale data centres using huge amounts of energy even if the solutions they power can save energy. • Data breaches, cyber security risks on rise, driven by trend towards cloud computing.	• Standards or Voluntary Agreements for companies to power their energy-hungry data centres from 100% renewable energy. Some tech firms have committed to this e.g. the 100% renewables commitment made by Google, Microsoft, Apple, Facebook, Salesforce, BT Group and others. • Policy role for standards to eliminate threats, technology risks, and safeguards for cloud environments. Work of the RSA on Cloud Security Alliance (Cloud Security Alliance, 2017) could be leveraged.

Source: PwC

As these examples demonstrate, governments have a critical role to play to minimise unintended consequences and ensure the 4IR is a responsible and sustainable revolution. History has shown how government R&D investment programmes, coupled with access to government computing power, have played an instrumental role in catalysing innovation and private markets to create common goods, including big breakthroughs in space, pharmaceuticals, and technology. There are several ways the public sector can also help in the 21st Century. Governments can identify social, economic or environmental externalities that the market does not capture, and come up with regulatory or market mechanisms to address these market failures. Policy mechanisms can be broadly categorised into market-based measures, regulation, and direct action. Below, as an illustration, we use categories for policy mechanisms that could help achieve SDG 7 (Affordable and Clean Energy) and SDG 13 (Climate Action). These options, however, have wider implications across many of the other SDGs due to the interconnected nature of the Global Goals, see Table 2 below.

Table 2: Policy mechanisms description, generic and 4IR examples and indicative pros and cons from a policy perspective

Policy mechanism	Type of intervention	Brief description	Generic example	Pros from a policy perspective	Cons from a policy perspective	Example 4IR application
Market-based measures	Fiscal instruments (taxes and subsidies)	To dis-incentivise (or incentivise) activity in certain areas or sectors through fiscal instruments	Carbon or landfill taxes; subsidies for renewable energy.	-Price (tax or subsidy) level is generally known in advance. -Relatively straightforward to design and administer. -Encourages innovation by firms or individuals in order to avoid the tax. -Raises revenue that can be spent on pollution mitigation. -Efficient from a market perspective as it internalises the external cost of pollution.	-Quantity of reduction (or increase in activity) is not known so tax take or total subsidies are uncertain. -Can be difficult to accurately price the external cost (and therefore set the accurate tax level). -May encourage flight of companies to other countries or jurisdictions.	Subsidies for ‘tech for good’ applications. Taxes on ‘damaging’ or harmful emerging tech applications.

Market-based measures	Cap and trade (emissions trading systems)	To lower, and limit, the volume of emissions or pollutants by capping emissions. Permits are then used for market participants to trade emissions permits.	Emissions Trading Systems; US Acid Rain Programme.	-Level of activity (or reduction) is set (or capped) and will be met over a given timeframe. -Encourages innovation by firms or individuals in order to financially benefit from the system. -If permits are auctioned, raises revenue that can be spent on pollution mitigation. -Efficient from a market perspective as it internalizes the external cost of pollution.	- Price of that quantity of activity level is not known in advance and could turn out to be expensive. - Can be difficult to determine the appropriate number of permits. - Administrative costs associated with implementation can be high.	Blockchain, and IoT, enabled cap and trade systems.
Market-based measures	Voluntary agreements	Facilitated by governments or regulators for certain sectors or areas, which can be looser but sometimes offer effective low-cost changes where industry is ready and willing to cooperate.	Sector agreements to reach 100% renewables electricity generation.	Minimal burden of administration/reporting upon government. Often is perceived as a more collaborative solution working with the companies who will affect change. Showing commitment to voluntary agreements can facilitate healthy competition between organisations to appear environmentally conscious.	Companies may not cooperate, or set too lax a target that is within "business as usual" reach. Challenges related to accountability if organisations are not obliged to report against performance.	Voluntary agreements as regards AI standards and defining what 'harmful AI' is and how it should be monitored.
Regulation	Standards	To limit or specify levels of emissions, pollutants, efficiency, or energy use. Public procurement can also include standards on supply chains for firms or products to meet.	Car emissions or exhaust standards. And procurement environment and / or social requirements..	Standards can create an industry-wide target for manufacturers to meet. They also create a level playing field within markets. Dates for introduction can be agreed with organisations well in advance to give them time to prepare - this can also shape research and development trends.	Industry lobbying can ensure improvements in standards remain incremental in nature and do not achieve the step-change in activity required In the context of newly produced products, does not address impact of existing products (e.g. existing cars on the road).	Standards, and potentially limits, around how emerging technologies are designed and used. Standards on energy use/efficiency for emerging technology.

Regulation	Mandatory phase-out	Instruments or laws to ban certain activities or products over time.	The incandescent light bulb in the European Union.	Can drive change more quickly and provides an end-date for use.	Cost of change can be high if not effectively planned and monitored.	Mandatory phase-out of non-autonomous electric vehicles in city centres by the 2040s.
Direct action	Public research	Using government research funding and institutes to initiate or accelerate solutions.	AI applications in climate modelling and weather prediction, advanced material science for clean energy sources and storage, carbon sequestering techniques etc.	Provides early stage research-led approach to solution ideation, which can then be scaled. Upskills a potential workforce in the areas chosen.	Public institutes, although often effective, might not always be the best place to innovate solutions. Can be difficult to translate research into practical solutions for implementation.	Research into 'tech for good' applications with a focus on individual and 4IR technologies in combination.
Direct action	Retraining and skills	To manage the flow of resources from contracting sectors to fast-growing sectors.	Initiatives might include retraining, skills development, and provision of transitional support facilities.	Helps achieve buy-in to structural change and also ensures better resource-use both during and after a transition.	Training needs to be tailored to where jobs are likely to be found. Poor retraining and reskilling can exacerbate resistance to change.	Retraining oil and gas or mining workers into areas including advanced materials clean tech. Reskilling manufacturing workers to use 3D-printing and IIoT systems.
Risk capital	Innovation finance	To provide start-up capital and/or incubation services to accelerate innovations from R&D through to commercialisation	Competitive innovation (grant) funds, start-up accelerators and incubators, innovation prizes	Tried and tested public finance model, which enables the best ideas to emerge from wherever they are. Corrects market failure where unproven tech cannot attract finance	Does not address system-wide barriers and may risk creating unlevel playing field if governments 'pick winners'	Innovation Fund or Accelerator for promising new 4IR enterprises at start-up stage
Risk capital	Pricing support mechanisms	To provide guaranteed demand or pricing for products, services or assets which the private sector cannot forecast with sufficient certainty	Availability-based pricing (infrastructure), offtakes, power purchase agreements and strike prices, guaranteed market demand (e.g. GAVI)	Provide certainty, usually long-term, enabling institutional investors to invest at scale and with patience	Relies on government to identify solutions which subsequent market demand may not justify	PPAs for 4IR-enabled distributed renewable energy grids and market places, guaranteed rental/purchase of future tech assets or products

Risk capital	Other guarantees and insurances	To remove other specific uncertainties or risks which are too high for the private sector to be able to absorb, which prevent investm ent	FX risk buy-down, political insurance, third-party default guarantees	Reduce specific risks which the private sector cannot bear in a less distortionary way than direct finance. Especially useful for emerging, frontier or volatile economies	Complex and requiring highly technical financial expertise; uncertain cashflow impacts on public finance and difficult to communicate	Default insurance for investors looking to provide loan finance to growth 4IR enterprises with social and environmental impact
Risk capital	Patient and concessiona l capital	To provide additional capital investment in equity or debt which the market is not providing, sometimes at below-market rates of risk-adjusted return	Concessional loans, long-term tenor loans, anchor equity investment	Provides a signalling effect to private investors, may also enable commercial models which would otherwise not survive on market terms but have positive environmental impact	Distortionary by design, and therefore need smart use and targeting at high impact areas. Require investor skill sets	Anchor investment in major, long-term asset-based 4IR infrastructure; equity investment into 4IR for good enterprises

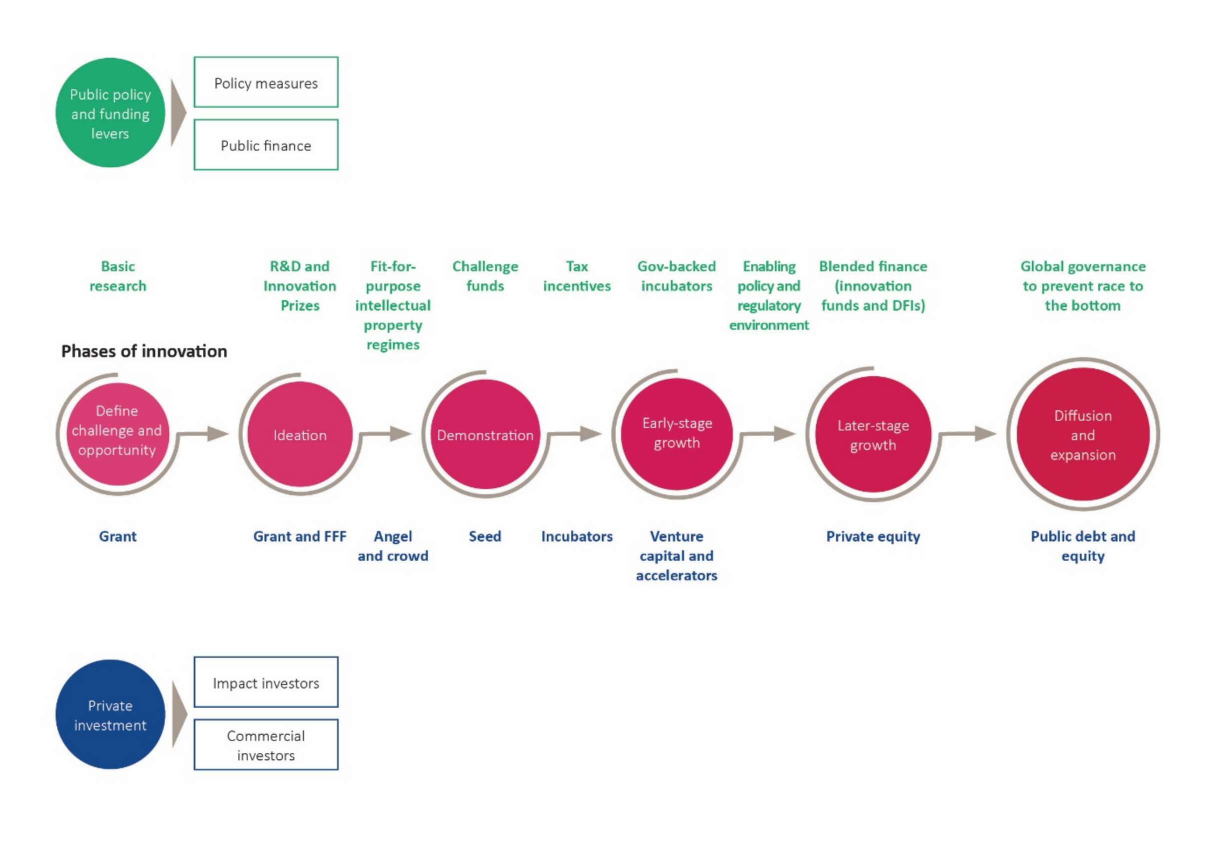
Source: PwC

Scaling 4IR innovations that tackle key social and environmental challenges

In addition to these broad mechanisms and levers, governments and policy makers can also take a number of direct focused steps to support breakthrough innovations and promote commercialisation. These include: targeted research and development (R&D) funding and tax incentives; innovative public-private financial instruments including patient capital and risk underwriting; technical advisory support; and facilitation of connections and partnerships between entrepreneurs and large-scale commercial businesses with the knowhow to scale innovations.

Figure 3 below outlines, in a simplified chronology, the range of public policy levers and accompanying sources of private capital, which can help to accelerate innovations on a pathway from ideation to scale. In parallel, institutional moves need to be sequenced across the innovation cycle to maximise levers and finance options. For example, innovative start-ups can struggle to gain finance from Venture Capital (VCs), who often prefer proven technologies with track records on which to base investment decisions. There can, therefore, be a critical role for angel investment, incubators, patient capital and government-backed innovation vehicles and incentives.

Figure 3: Public policy and phases of innovation



Source: PwC

To realise the overarching opportunity of accelerating and scaling 4IR technologies - in a way that provides innovative solutions that help to realise the SDGs - the full range of sources of public and private capital will need to be drawn from. This will include, private, philanthropic, corporate and public investment; and it may include both traditional commercial investment seeking primarily financial returns, as well as innovative impact investments which seek a blend of financial and (social and environmental) impact returns.

This scaling will require a range of solutions and applications, both standalone and in combination, across most - if not all - sectors to achieve transformative goals. Some examples and emerging applications include:

For Energy, one of the key 4IR innovation challenges is for technology breakthroughs to enable a next-generation clean distributed grid with virtual power plants aggregating millions and soon billions of emerging renewables sources, all optimised by AI and machine learning, with blockchain and IoT enabled peer-to-peer trading.

In Transport, advanced materials including graphene and nano-solutions are close to underpinning battery breakthroughs for inexpensive, quick-charging energy-dense batteries.

This could disrupt the market for carbon-intensive internal combustion engines and make electric cars both performance- and cost- competitive.

In Manufacturing, circular global supply chains could be more quickly realised utilising the "Industrial Internet of Things" (IIoT) coupled with AI, robotics, virtual reality, drones and advanced materials.

In Retail, technology could fundamentally transform resource-heavy consumption, developing from a new system of virtual shopping, point-of-use 3D printing, blockchain, AI and IoT-enabled supply chain transparency and accountability, and circular and sharing economy models.

In Finance, Fintech, including AI, blockchain and IoT, enable increased access and decentralisation of the financial system to serve the unbanked and underbanked, improve market integrity and could perhaps provide early warning signals of systemic financial strains.

In cities, the IoT and bioengineering can be utilised to alter space and integrate operational systems to make lighting, heating, deliveries and waste collection more efficient based on real-time demand. Elsewhere, Blockchain and AI technologies can help automate planning processes and property developments. Moreover, drones, 3D-printing and robots can be used to construct new multifunctional buildings in a more timely and resource-efficient manner. See our 4IR report on Sustainable Emerging Cities.[2]

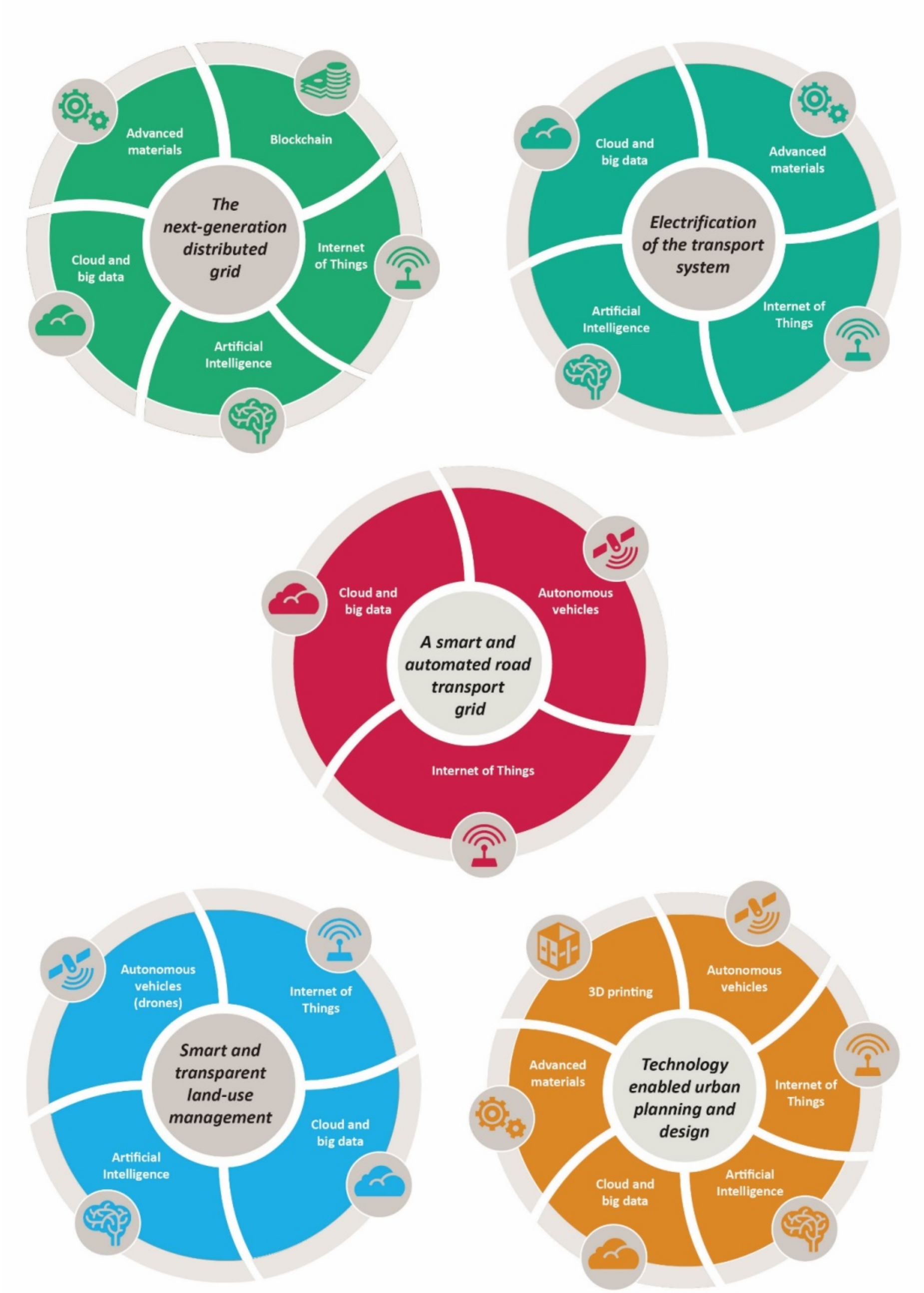
These examples are only a few illustrations of the transformations to traditional sectors enabled by 4IR technologies that can also lead to positive social and environmental impact. In many cases emerging solutions, across sectors, are realised by fusing together a number of 4IR technologies - with AI and data, IoT and blockchain in particular often coming together as a "4IR gearbox" for change. The potential is there for 4IR technologies to come together to drive broader structural changes in our cities, across our transport and energy networks, to our financial markets, and through our industrial value chains. This is why it is important that innovation initiatives go beyond investment into a single technology or specialisation, but also create opportunities for connection and collaboration to unlock game-changing outcomes.

To illustrate this further, in the recent PwC Innovation for the Earth Report,[3] we identified five key 4IR innovation game-changers for two of the SDGs 7 and 13 (Affordable and Clean Energy, and Climate Action) which fuse together 4IR technologies and present substantial potential to underpin a zero-net-emissions economy (Figure 4).

2 PwC (2017a)

3 PwC (2017b)

Figure 4: Five emerging game-changing climate solutions building on multiple 4IR technologies



Source: PwC (2017b)

Recommendations for the G20

Bringing this together, below we set out some initial steps to consider. These recommendations would involve the G20, together with international organisations, collaborating with multiple stakeholders from politics, industry, academia and the civil society. G20 led, and supported, collaboration, can help ensure that the 4IR supports global growth which is inclusive, sustainable, and aligned to delivering the SDGs.

Overarching recommendations

1. ***The G20 should champion international technological governance structures to support 4IR-enabled solutions for the SDGs.*** This would provide the policy and enabling environment to enable scaling of 4IR technologies that contribute towards achieving the SDGs. Open architecture models ought to be explored to enable sharing technological advances and data. Intellectual Property considerations will also need to be addressed. Governance structures and policy safeguards will want to consider international competitiveness, particularly to avoid a "race to the bottom" in terms of tech firms' jurisdiction for corporate, fiscal, and legal objectives. Building public trust will also need to be a central principle of 4IR governance structures.
2. ***The G20 should identify and promote essential safeguards to ensure a Sustainable 4IR*** to minimise unintended negative consequences (e.g. developing international standards and regulations for blockchain, IoT devices, cloud data servers etc.). The Global Blockchain Forum (The Chamber of Digital Commerce, 2017) – an international body whose mission is to shape international blockchain policy – is a step in this regard. Appropriate safeguards will also need to be developed to ensure security of data and digital identities.
3. ***The G20 should promote a coordinated effort by governments and regulators to identify and manage systemic risks emanating from the 4IR.*** The focus would be the effect on financial institutions in particular and financial stability more broadly. The Bank of England and Financial Stability Board's work on climate risk and financial stability is an example on which to build (Bank of England, 2017). These efforts could be broadened to include how tech investments and new business models are recognised and are being accounted for, as well implications for tax policy and fiscal stability. Regulators will also need to be modernised – working with RegTech innovators to harness 4IR solutions for their own systems to provide adequate oversight and supervision to sectors in the midst of rapid and structural transformation e.g. Fintech and Energy.
4. ***The G20 should encourage countries to develop responsible technology policies,*** which would include developing a definition and standard as regards the 'misuse of AI' as well as employing social and environmental considerations in countries' national digital strategies. Governments should employ a joined-up approach to the 4IR within

their country, including provision of interdepartmental oversight across government functions to ensure technological social and environmental safeguards, and opportunities, are managed in a holistic way. One specific lever could be for governments to require their procurement supply chains to meet specific standards, or safeguards, to tender for public sector contracts.

5. ***The G20 should encourage 4IR technology experts to work with disciplines beyond computer science and engineering to develop governance and policy solutions.*** Many of the emerging technologies appearing could have enormous impacts on the ways we live and work. There is a danger that solutions are designed and developed from a small group of people with a limited perspective. There will increasingly need to be significantly more interaction between technology practioners, domain experts, and a broader range of disciplines including philosophy, law, psychology and policy etc. to enable holistic mechanisms and solutions to be developed and deployed.

Research & Development and Education

6. ***The G20 should make a call for G20 governments to commit large scale basic and applied R&D investments towards priority Sustainable 4IR challenges.*** Coordinated and targeted large scale fund commitments are required, encouraging research and funding collaboration on ‘4IR for Good’ between industry, academic and government research agencies. The efforts of Mission Innovation (Mission Innnovation, 2017) to set ambitious targets and coordinate investment across over 20 countries for clean energy solutions is one example.

7. ***The G20 should steer basic research funding and priorities to encourage interdisciplinary research that bridges technology, social and environmental disciplines.*** Multi-disciplinary education and research programmes are vital to fuse together technology, earth and social sciences. This would include integrating sustainability and ethics into the curriculum of digital/technological/STEM-related undergraduate and graduate courses, and integrating technology into earth and social science curricula. MIT, for example, has taken on climate change as a ‘priority’, involving thousands of students, a third of the faculty, and more than 40 start-ups. In addition, Stanford University has developed a suite of 1-credit ‘Big Earth’ courses that use big data analytics to examine or solve questions about the planet (Stanford University, 2017). School children will also need to be fully engaged and trained for the 4IR.

8. ***The G20 should promote national and international PPP initiatives, programmes and funds to unlock and accelerate ‘4IR for Good’ innovation.*** This would include innovative public-private partnership finance solutions to support early stage commercialisation of 4IR for social and environmental impact solutions, including risk finance (grants, concessional debt and equity), innovation prizes and challenge funds to

promote ideation, and government backed incubators and accelerators to support pioneering new companies and ventures to scale.

9. ***The G20 should promote the establishment of a 4IR knowledge hub,*** a real-time central knowledge hub (driven by 4IR technology) that would democratise critical 4IR knowledge and data for business and society. The scope of this work could include, but would not be limited to: sharing thinking and information on 4IR developments early in the process; curating and consolidating standards in consumer markets across countries; disseminating information about social and environmental impacts; a data-library, including providing a central database of 4IR-related academic and other research work and data. The hub could also usefully flag emerging risks and important policy questions as technologies mature.

Engagement and awareness raising

10. ***The G20 should openly and actively promote a global "tech for good" campaign*** to educate people and industry about how technology can be a force for good. The campaign could promote and disseminate, in conversation and collaboration with the media and technology firms, information about how unintended consequences and adverse effects are being mitigated, and how technologies are being developed and deployed to realise social and environmental goals. Education can raise awareness, build necessary 4IR skills in schools and universities, as well as alleviating the fear of the unknown and the generation gap.

11. ***The G20 should actively champion companies to support a Sustainable 4IR.*** Governments, with industry input, should create policy and incentives that encourage corporate policy and governance for responsible technology, including developing business charters for responsible technology. The private sector also should be encouraged to advance, build-in and optimise the impact of technologies on sustainability in companies' technology strategies. Entrepreneurs and designers need increasingly to embed sustainability into design principles so that mainstream 4IR technologies are in fact 'smart'. Companies should be encouraged to collaborate, with the UN (United Nations, 2017), across their industry, and with regulators, to aid standard setting e.g. consensus protocols and targets.

Data, Algorithms and Ethics

12. ***The G20 should support the creation of a better data environment - including access and data skills - to maximise the opportunity of big data and machine learning for sustainable 4IR solutions***. As data is one of the key building blocks to drive innovation in the 4IR, effort needs to be devoted to improving the systems by which we define, gather, access and manipulate data. This includes government initiatives for open public data, and policy frameworks (or agreements) to make strategic data available to specific

users - with associated safeguards – for the purposes of big data and machine learning to tackle societal and environmental challenges. It also requires investment in skills and capability at every level, from establishing basic data literacy in schools, through to fostering the uptake of sector-specific applications within industry and the cultivation of world-leading big data and machine learning knowledge and capabilities within universities.

13. ***The G20 should develop a policy framework that supports tech companies, research institutes and universities to manage potential systemic bias in algorithms***. Crowd-sourced raw data that tech companies use in their algorithms typically reflects the biases and prejudices inherent in society at large. This has led to a series of instances where algorithms have produced results that have been perceived as discriminatory (e.g. on race or gender grounds). Policy frameworks are needed which balance concerns around unfairness and discrimination in publicly-sourced big data with the technical and ethical challenges as regards monitoring, and potential censoring, of data. The G20 should support an initiative or commission for academics, technologists and other stakeholders to determine a concrete process to hold algorithms and their owners accountable, whether that's algorithmic transparency, oversight commissions or another form of algorithmic accountability to ensure certain values are encoded and implemented in the algorithmic models, from avoiding discrimination to optimising for minimal energy usage. In addition to transparency, frameworks for explainabiliy and validity testing ought to be developed.

14. ***The G20 should consider and evaluate ethical aspects of the relationship between people and machine systems***, which would include implications for privacy, scope and boundaries to human / digital augmentation and the rights of people. This should include instituting policies and procedures that ensure that ethical aspects of cyber-physical systems are identified, evaluated and appropriately addressed. Security of data and digital identities will also need consideration.

15. ***The G20 should recognise and support the work being done to give every person in the world a unique digital identity.*** There is currently an initiative that directly addresses the UN sustainability goal 16.9: "by 2030, provide legal identity for all, including birth registration". ID2020 (ID2020, 2017), in partnership with the Gavi foundation (Gavi, 2017) (an alliance who collectively vaccinate circa 93% of the world's population), aims to harness the 4IR to give a digital identity to everyone. This initiative would secure recognition before the law and safeguard individual rights and access to justice, public services, banking, visas etc.

Introduction to xAI

Past is not prologue when it comes to artificial intelligence. Accelerating improvements in AI algorithms are enabling breakthroughs of applications across domains, leading to ubiquitous systems that sense, think, and act on their own. Technical advancements are resulting in more complex models that allow computers to detect patterns in information but have limitations in human interpretability. Computers have no sense of morality, so difficult to explain models can have hidden biases or issues that humans cannot vet and have the potential to cause significant harm to society. For example, if a loan approval system was used to automate the decisions about whether loans are approved or denied, a clear reason must be given to customers whose applications are denied. In certain black box AI models used in the past, demographic information influenced the system, resulting in bias-prone decisions. End users (in this case, loan applicants) must be given rational explanations as to why a system decided in a certain way. AI models often have stronger performance than traditional approaches, but have limited ability to provide these much needed rational explanations.

This need for more interpretable AI has launched a field called "Explainable AI" or "xAI". xAI research combines expertise from multiple disciplines (e.g. computer science, sociology, psychology, statistics, etc.) and aims to find methods for AI systems to explain their decisions in a way that humans can easily understand. xAI can be broken down into three main components:

- **Explainability:** Each individual level result of a model needs to have reasoning on the particular answer provided
- **Transparency:** The inner workings of a model structure should be accessible to the user to allow human understanding of the patterns detected by the AI
- **Provability**: A model is provable when the user can test that an effective percentage of possible predictions or decisions made by the model are correct

The xAI field is rapidly expanding, with agencies such as DARPA, Open AI, and the Future of Life Institute heavily investing in xAI collaborations ***and xAI becoming an important part of many country-wide AI strategies***. The effective development, use and dissemination of xAI needs to be a global effort to mediate the appropriate use of AI.

Finally, we propose that the T20 considers establishing a dedicated taskforce on "Sustainable 4IR" to enable the T20 to provide expert input to G20 policymakers on this crucial cross-cutting area for cooperation and policy-making. The taskforce would include recognised global experts across emerging technologies, social and environmental challenges, and industry-specific experts. It would recommend solutions and governance structures that are agile and flexible enough to navigate and support rapid 4IR innovation - across the digital, physical and biological domains of the 4IR - in a sustainable way. The taskforce would be linked to, and work closely with, the Digital Economy taskforce and the 2030 Agenda Taskforce, but with a specific mandate to steer the 4IR (incl. the digital economy) to meet the SDGs.

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